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## Article

# Agronomic Traits in Oilseed Rape (*Brassica napus*) Can Predict Foraging Resources for Insect Pollinators

Stacey M. Fairhurst <sup>1,2,\*</sup>, Lorna J. Cole <sup>3</sup> , Tereza Kocarkova <sup>4</sup>, Catherine Jones-Morris <sup>1</sup>, Andy Evans <sup>2</sup> and Gail Jackson <sup>1</sup> 

<sup>1</sup> School of Geosciences, The University of Edinburgh, Crew Building, King's Buildings, Alexander Crum Brown Road, Edinburgh EH9 3FF, UK; cjonesmorris@outlook.com (C.J.-M.); g.jackson@ed.ac.uk (G.J.)

<sup>2</sup> Agriculture, Horticulture and Engineering Sciences, Scotland's Rural College (SRUC), King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK; andy.evans@sruc.ac.uk

<sup>3</sup> Integrated Land Management, Scotland's Rural College (SRUC), Auchincruive Estate, Ayr KA6 5HW, UK; lorna.cole@sruc.ac.uk

<sup>4</sup> Independent Researcher, King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK; kocarkova.t@gmail.com

\* Correspondence: sfairhu2@ed.ac.uk

**Abstract:** Mass-flowering crops, such as oilseed rape (OSR; *Brassica napus*), provide pulses of nectar and pollen, helping to support pollinators and their pollination services in agricultural landscapes. Despite their value to declining pollinators, varietal in-field OSR testing focusses on agronomic traits, with floral resources being largely overlooked. OSR has a high varietal turnover, and consequently, floral resource data collected for a specific variety quickly become redundant. Here, we explore the potential to predict floral resource availability using agronomic trait data routinely collected in varietal trials. To build predictive models, we investigated the relationships between agronomic traits and pollen and nectar availability in 19 OSR varieties. Nectar quality was positively influenced by early vigour, as well as winter hardiness in conventional varieties and stem stiffness in hybrid varieties. Pollen quantity was driven by different traits, with early maturation having a negative impact in conventional varieties and resistance to lodging having a positive impact in hybrid varieties. Our study highlights the potential to predict floral resources using agronomic trait data, enabling the rapid assessment of these key resources in future OSR varieties without costly sampling. Agronomic traits relating to increased nectar quality were also agronomically favourable, indicating benefits to both pollinators and growers. The inclusion of modelled floral resource data in recommended varietal lists would enable growers to make informed decisions about varietal selection based on local pollinator populations.

**Keywords:** *Brassica napus*; oilseed rape; floral resources; agronomic traits; pollinators; pollination services; sustainability



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## 1. Introduction

### 1.1. Pollinator Decline

There has been considerable concern over the decline of insect pollinators and the impact of depleted pollination services on our crops, wildflowers and trees [1–5]. Globally, more than 87% of flowering plant species profit from animal pollination [6], and 70% of leading crops have the potential to increase yields and/or quality as a result of animal-mediated pollination [7]. Pollinator declines, therefore, seriously threaten biodiversity and food security. Causes for this decline include the destruction of semi-natural habitats, such as hedgerows and wildflower-rich habitats [8]; increased insecticide use [9]; and climate change and invasive species and pathogens [10]. However, the key contributing factor is the decrease in floral resource availability linked with agricultural intensification [2,7,11].

### 1.2. Interdependence of Oilseed Rape and Insect Pollinators

Oilseed rape (OSR) is the third-largest source of vegetable oil worldwide. In Europe, it is the largest oilseed crop, cultivated on 34.9 million hectares in 2019 and producing 18 million metric tons of seed annually [12]. With an estimated global commercial value of over \$7.5 billion per annum [12], OSR is subject to an intensive commercial breeding programme. While OSR is capable of self-pollination, insect visitation increases crop yield and, consequently, economic value [13–15]. Insect pollination increases oilseed rape (OSR; *Brassica napus*) yield [16–18], seed weight [18,19], and quality [13], indicating a strong interdependence between OSR and pollinators. Evidence is mounting that a range of insect-pollinated crops are experiencing pollination deficits (i.e., losses of yield/quality as a result of inadequate pollination services) [20,21], indicating that effective management of pollination services will have clear agronomic benefits [21]. OSR provides insects with nutrient-rich resources, producing nectar and pollen as a reward for insect-visitors in exchange for pollination services [22]. In addition to amino acids and minerals, nectar provides an essential source of carbohydrate-rich sugars (sucrose, glucose and fructose) to fuel flight for foraging, nesting and mating activities and other physiological processes [22]. Pollen provides a further reward, adding proteins, lipids and vitamins to the diet for longer-term benefits [23]. For example, bees directly invest foraged pollen in the next generation [24,25]. A single western honey bee (*Apis mellifera*) colony can collect as much as 120 kg of nectar and 20 kg of pollen annually [26].

Mass-flowering crops, such as OSR, soybean and sunflower, offer large quantities of floral resources, albeit in concentrated time periods [27–29]. These crops can positively affect pollinator abundance by increasing the nest densities of wild pollinators [30–32]. Westphal, et al. [33] and Jauker, et al. [34] report positive effects of OSR during the early colony growth of bumble bees and solitary bees. However, this growth did not translate to reproductive success (the presence of males and/or queens), potentially due to ‘hunger gaps’ later in the season [35]. By providing forage at different points in the season, OSR could play a fundamental role in protecting pollination services as part of an integrated land management strategy, in conjunction with agri-environmental options, to enhance spring (e.g., hedgerow creation and restoration) and summer (e.g., flower-rich field margins) resources [35–37]. Despite this, variety selection in OSR is primarily driven by agronomic factors, and their potential to provide forage for pollinators remains largely unconsidered by growers.

### 1.3. Oilseed Rape Breeding Programmes

OSR varieties are bred in one of two ways. Conventional varieties are ‘open-pollinated’ using traditional line-breeding methods, selecting parent plants with favourable, heritable traits. Restored hybrid varieties are created by crossing male-sterile (female) plants with pollen-producing, fertile (male) plants to produce seeds with restored male fertility [38]. New varieties result from lengthy research by breeding companies, creating thousands of lines before selecting the highest performing varieties. New varieties must be ‘morphologically distinct, uniform and stable’ with performance measured against yield, oil quality and desirable agronomic traits [39]. Since new varieties compete to outperform currently listed ones, duration on the list is typically short (e.g., two to three years). Of the 26 OSR varieties that constitute the 2019 list, 15 are first- or second-year recommendations [40].

### 1.4. Agronomic Traits of Oilseed Rape

It is widely known that varietal differences in floral resources exist in winter OSR [41,42]. However, their value to pollinators is not currently considered within breeding or varietal recommendation programmes. Recent studies have focused on differences in floral resource availability across specific varieties [43] or breeding systems [44,45]. However, the literature does not extend to identifying if the agronomic traits displayed by OSR varieties influence resource availability. Fulfilling this knowledge gap may not influence breeders to develop ‘pollinator-friendly’ varieties over high-performing varieties. However, it may

allow conscientious growers to make informed decisions about variety selection, to exploit local pollinator communities for increased yield.

Evaluating floral resources involves sampling nectar and pollen for each OSR variety, which is time-consuming and requires specialist training and equipment. Furthermore, due to the high turnover of OSR varieties, annual surveying would be required to quantify floral resources in new varieties. An alternative, more cost-effective means of evaluating floral resources may be to explore the relationship between measured OSR agronomic traits and resource availability. During infield testing, varieties undergo assessments for several important agronomic traits, including yield performance and disease resistance. In the UK, these traits are compared across varieties by the trial manager throughout the growing season and ranked for each trial site. Alongside yield performance results, agronomists use them to recommend specific varieties, dependent on growers' needs. For example, they would select varieties with a high stem stiffness score on a farm exposed to high winds. Plant traits have been used previously to successfully predict nectar sugar productivity [46] and to quantify pollen [47] across various plant species. By narrowing the focus to investigate differences across agronomic traits rather than varieties, it may be possible to identify if any specific trait, or combination of traits, impacts nectar and pollen availability. These 'favourable' trait combinations could then be used to predict floral resources in future varieties.

### *1.5. Aim of this Study*

In this study, we set out to answer the following question: can we predict floral resource availability using agronomic trait data, which is routinely collected as part of varietal recommendation testing? To provide answers, we quantified floral resources (i.e., nectar and pollen) in 19 varieties of winter OSR, currently undergoing varietal recommendation testing. We then modelled the relationship between key agronomic traits (e.g., earliness of maturity, stem stiffness and winter hardiness) and pollen and nectar availability to build predictive models that would determine resource availability in future varieties. The ultimate aim would be to include a criterion of 'floral resource value' in future OSR breeding programmes and varietal recommendation initiatives.

## **2. Materials and Methods**

### *2.1. Study Site*

The study was conducted in 2019 at the Agriculture and Horticulture Development Board's (AHDB) North Region Oilseed Rape Recommended List (RL) field site in Midlothian, Scotland (NT 251659). Winter OSR varieties were replicated across three randomised blocks, with two plots per variety per block (i.e., a total of six plots per variety across the trial site). Each plot measured 10 m × 4 m, with a seed rate of 60 seeds/m<sup>2</sup>. Double guard plots of identical dimensions provided separation between breeding systems. All plots were subject to conventional agrochemical treatments to control for pests and pathogens. To provide a comprehensive database for OSR traits across varieties, including annual variation in these traits, surveying focused on 19 established varieties (ten conventional/open-pollinated, nine restored hybrids). All varieties selected for this study have undergone two years of regional in-field testing by the Agricultural and Horticultural Development Board (AHDB). They have gained Plant Breeder's Rights, a prerequisite for the seed reaching market, and have been present on the National Recommended List (RL) for at least two years [39].

### *2.2. Environmental Conditions*

As environmental conditions may influence nectar production [48,49], temperature and relative humidity data were collected using a Delta-T WS-GP2 weather station (Delta-T Devices, Cambridge, UK), located in the adjacent field (approximately 150 m). These data were used to calculate the short-term (i.e., three hours) atmospheric vapour pressure deficit (VPD) before sampling rather than the long-term environmental effect. VPD is the

difference between the saturated and actual water vapour pressure of the air and is often termed as its ‘drying power’. Therefore, it may affect the water content of the nectar (and hence the sugar concentration) and potentially also the rate of nectar production.

*VPD* is calculated from temperature and relative humidity using the Tetens’ equation, first to calculate saturated vapour pressure (*SVP*) [50]:

$$SVP = 0.61078 \exp\left(\frac{17.27T}{T + 237.3}\right) \quad (1)$$

Then:

$$VPD = SVP \times \left(\frac{1 - RH}{100}\right) \quad (2)$$

where *T* is the temperature in °C and *RH* is relative humidity (%).

### 2.3. Nectar Collection and Quantification

Nectar was sampled from five flowers per plant. Two plants per variety were sampled from block one and one plant per variety from blocks two and three (i.e., four plants for each of the 19 varieties). Nectar sampling took place on dry days during peak flowering (24 April–2 May 2019), between 09:00 and 17:00 hrs. Sample times were split into ‘early’ (09:00 hrs), ‘mid’ (12:00 hrs) and ‘late’ (15:00 hrs) collection periods. Flowering phenology was similar across all varieties. All blocks were sampled at least once per collection period.

The standing crop of nectar present in unvisited, newly opened flowers was measured rather than the secretion rate [51]. Terminal stems with at least ten unopened flowers were used. The most recent flower to open on each raceme was marked using cut sections of drinking straws to eliminate flower-age-related disparity. All buds above the marked flower were enclosed in 15 × 35 cm tulle net bags (1 × 1 mm mesh) to prevent pollinator visitation. Bags remained in place for 36 hrs before sampling. Sampling was restricted to recently opened flowers (those above the marked flower), and only flowers with dehiscent anthers were sampled. Nectar was collected using calibrated 1 µL glass capillary tubes (Drummond Scientific Co., Broomall, PA, USA) [52].

Nectar volume was calculated by dividing the length of the nectar column in the capillary tube by the total length of the capillary tube [52]. Sugar concentration (°Brix) was measured in the field with a low-volume, temperature-calibrated refractometer (Bellingham & Stanley Ltd., Farnborough, Hants, UK). As the units of nectar volume (µL) and °Brix (% by mass) differ, multiplying them introduces significant errors at high percentages. To correct for this, mg sugar mg<sup>−1</sup> was converted to mg sugar µL<sup>−1</sup> using the polynomial model equation [53,54]:

$$\hat{y} = 0.00226 + (0.00937 x) + (0.0000585 x^2) \quad (3)$$

where *x* represents the sugar concentration (°Brix) and *ŷ* the predicted quantity of sugar (mg sugar µL<sup>−1</sup>). Total sugar per flower is calculated by multiplying mg sugar µL<sup>−1</sup> by total nectar volume.

### 2.4. Pollen Collection and Quantification

For pollen quantification, all three blocks were sampled. During a single day (i.e., 24 April 2019), anthers were collected from five plants per plot, totaling 15 plants per variety. Pollen from 15 flowers per variety was sampled (one flower per plant, five plants per plot, three blocks), giving a total of 285 flowers across 19 varieties. The stamens of *B. napus* flowers encircle the stigma in two sets: an inner ring of four, long, outwardly facing anthers and an outer ring of two, shorter, inwardly facing anthers. All anthers per flower were collected. To reduce pollen loss, anthers were collected shortly before anthesis and stored in a 1.5 mL Eppendorf tube until dehiscence. They were then preserved in 1 mL of 70% ethanol solution. Following the methods described by Ouvrard [45], pollen was harvested using ultrasonication (Fisherbrand S-Series FB15046, Fisher Scientific, Loughborough, Leics,



UK). Grains, dispersed into known volumes of 70% ethanol solution, were counted on a haemocytometer (Weber Scientific, Hamilton, NJ, USA).

### 2.5. Statistical Analysis

Before analyses, the effects of environmental factors (i.e., temperature, humidity and VPD) were investigated using simple linear regression. Following this, to determine if agronomic traits influenced floral resources, a stepwise bidirectional elimination selection approach using Akaike information criterion (AIC) was implemented to find the most parsimonious model (see Table 1 for a summary of all measured agronomic traits). As this study aimed to determine the potential to rapidly assess floral resources based on traits that are routinely surveyed in varietal selection traits, only such traits were explored.

**Table 1.** Summary and description of response and dependent variables used in regression analyses. Agronomic traits were measured during varietal infield testing by the Agricultural and Horticultural Development Board.

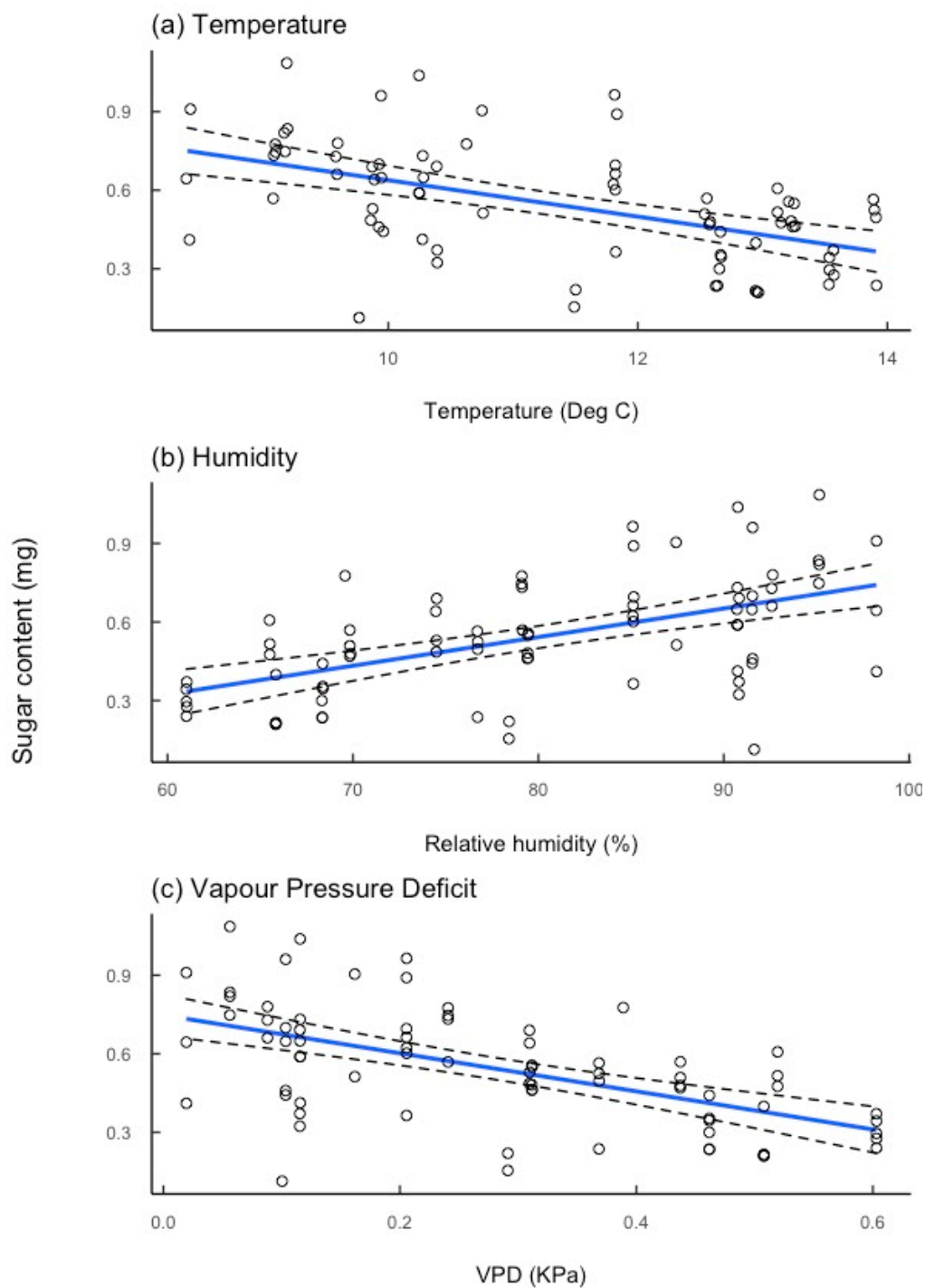
Variables	Description
Sugar quantity	Sugar mass per flower: mg sugar $\mu\text{L}^{-1}$
Pollen quantity	Number of pollen grains per flower
<i>Agronomic traits</i>	
Gross output	Tonnes per hectare
Seed yield	Tonnes per hectare
Oil content	Oil content %
Early vigour	Competition with weeds: 1–9 (1 very weak, 9 very strong)
Emergence	Date of full emergence: 1–9 (1 very slow, 9 very fast)
Establishment	Plants per $\text{m}^2$ following emergence: 1–9 (1 very thin, 9 very thick)
Lodging	Resistance to lodging (flowering): 1–9 (1 all plants lodged, 9 no lodging)
Stem stiffness	Resistance to lodging (maturity): 1–9 (1 all plants lodged, 9 no lodging)
Height	Average plant height at end of flowering: measured in centimetres
Earliness of flowering	Start of flowering: 1–9 (1 latest flowering plot, 9 earliest flowering plot)
Earliness of maturity	Canopy senescence before harvest: 1–9 (1 very late, 9 very early)
Winter hardiness	Survival rates throughout winter: 1–9 (1 complete loss, 9 no damage)

Temperature, humidity and VPD all had significant linear relationships with sugar per flower. To control for these climatic effects, VPD (i.e., the environmental variable with the highest  $R^2$  value: see Section 3.1) was therefore included as a predictor variable in our regression models for nectar. Bidirectional elimination stepwise multiple regression models for sugar per flower and pollen quantity were fitted separately for both breeding systems, using the agronomic traits in Table 1. Models with the lowest Akaike information criterion (AIC) were selected. Multicollinearity was checked using Variance Inflation Factors. All models presented  $\text{VIF} < 1.07$ , meaning no substantial collinearity was present [55]. Assumptions of normality of residuals were tested with Q–Q plots and Shapiro–Wilk tests. Statistical analyses were conducted using R version 3.6.1 [56].

## 3. Results

### 3.1. Environmental Effects on Sugar Quantity

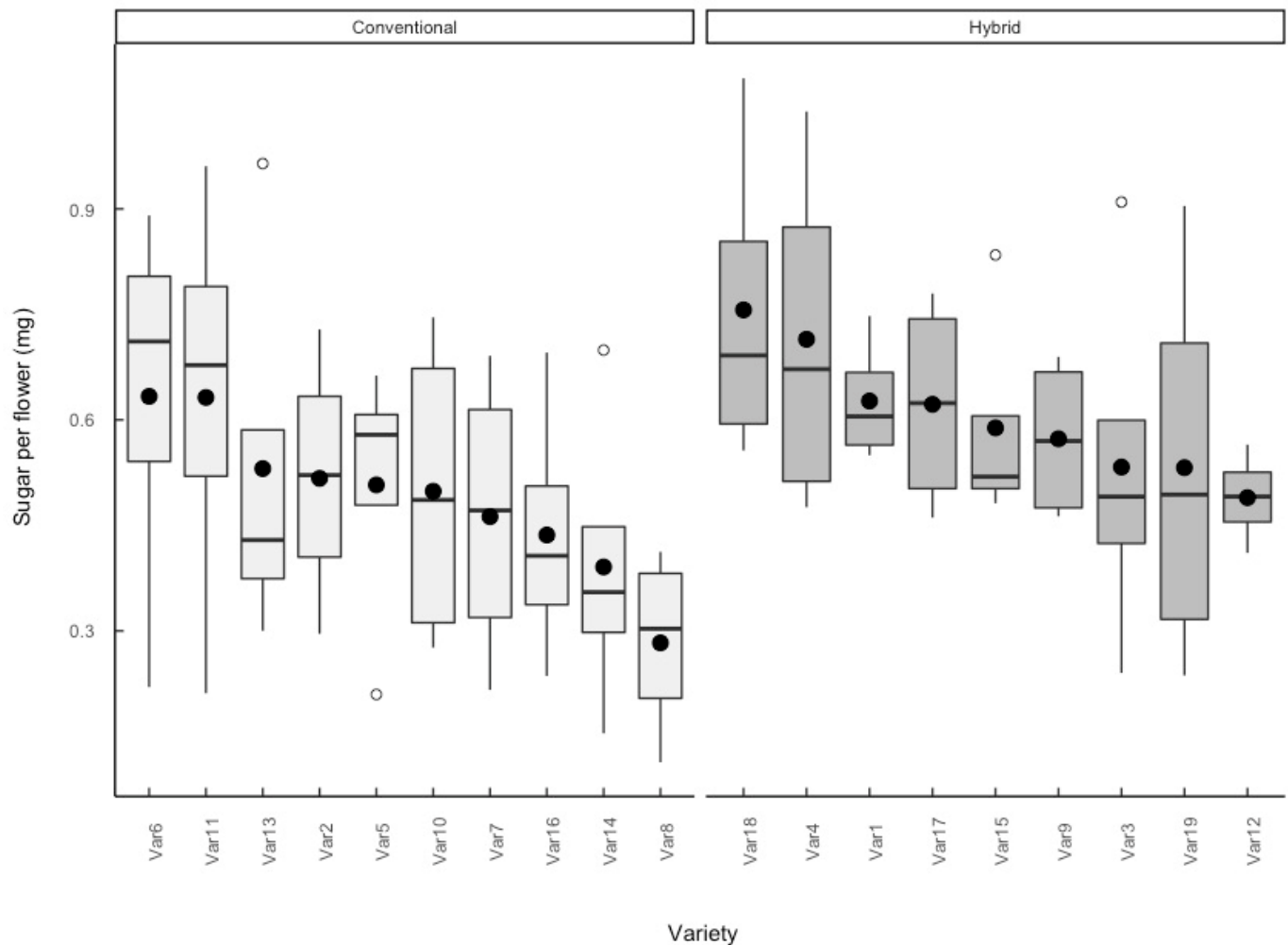
Simple linear regression showed that sugar content per flower significantly decreased with increasing temperature and vapour pressure deficit (VPD), whereas a positive relationship was found with relative humidity (Figure 1). These relationships were comparable for both breeding systems. Thus, to control for these effects, VPD was included as a predictor variable in further regression modelling.



**Figure 1.** The effect of (a) temperature ( $F_{1,74} = 28.56$ ,  $p < 0.001$ ,  $R^2 = 0.27$ ,  $n = 76$ ), (b) relative humidity ( $F_{1,74} = 32.73$ ,  $p < 0.001$ ,  $R^2 = 0.29$ ,  $n = 76$ ), and (c) vapour pressure deficit ( $F_{1,74} = 35.78$ ,  $p < 0.001$ ,  $R^2 = 0.32$ ,  $n = 76$ ) on sugar per flower (mg) of oilseed rape. Dotted lines show 95% confidence intervals of the mean.

### 3.2. Sugar per Flower

All varieties of OSR produced nectar. The mean amount of sugar per flower across all varieties was 0.54 mg ( $\pm 0.03$  SE). Hybrid varieties (mean 0.60 mg  $\pm 0.03$  SE) produced more sugar per flower than conventional varieties (mean 0.49 mg  $\pm 0.04$  SE;  $F_{2,73} = 8.50$ ,  $p < 0.01$ ). Inter-varietal differences in both breeding systems were similar, with both having a range of 0.85 mg of sugar per flower (Figure 2).

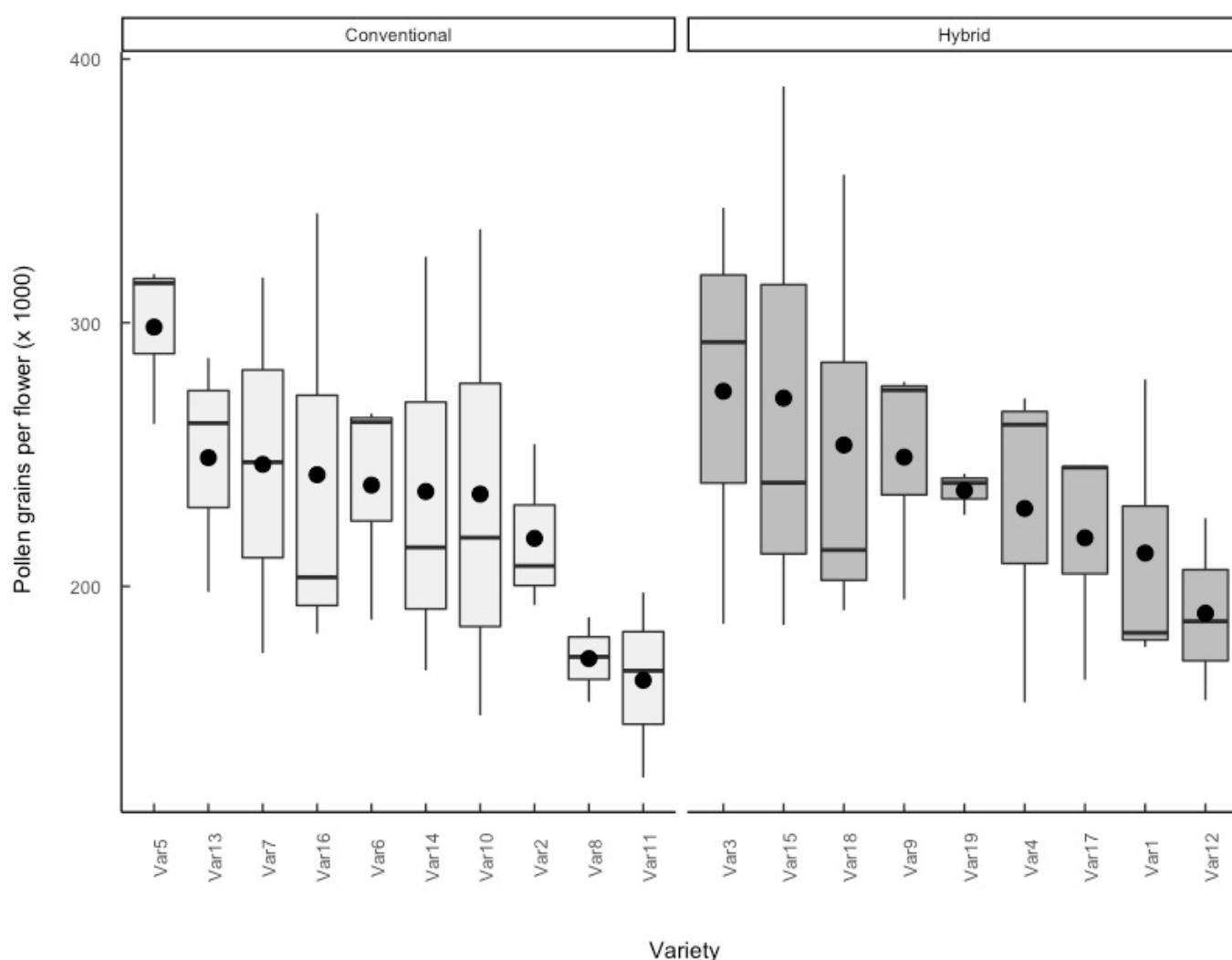


**Figure 2.** The quantity of sugar per flower in 19 oilseed rape varieties ( $n = 20$  flowers). Black circles represent the mean values. Boxes around the median show the interquartile range. Whiskers extend to minimum and maximum values. Variety names have been anonymised by request.

### 3.3. Pollen Grains per Flower

The mean number of pollen grains across all varieties of OSR was  $233,421 (\pm 8,061 \text{ SE})$  grains per flower. Hybrid varieties produced a greater number of pollen grains per flower (mean  $237,195 \pm 11,694 \text{ SE}$ ; range = 233,616 grains) than conventional varieties (mean  $230,036 \pm 11,279 \text{ SE}$ ; range = 214,063 grains), although this was not statistically significant ( $F_{1,55} = 0.27$ ,  $p = 0.61$ ). In both breeding systems, considerable inter-varietal differences were detected (Figure 3).





**Figure 3.** The number of pollen grains per flower in 19 oilseed rape varieties ( $n = 15$  flowers). Black circles represent the mean values. Boxes around the median show the interquartile range. Whiskers extend to minimum and maximum values. Variety names have been anonymised by request.

### 3.4. Prediction Models

As significant differences in sugar quantity were found between hybrid and conventional varieties, multiple regression analyses were conducted independently for the two breeding systems. Although the pollen difference between breeding systems was not statistically significant, separate analyses were also conducted for each breeding system to ensure consistency with analyses of sugar quantity. Multiple regression analyses examined the relationship between sugar quantity and pollen quantity per flower and the recorded agronomic trait values.

#### 3.4.1. Sugar per Flower

Stepwise multiple regression analyses were performed to investigate whether agronomic traits could predict the quantity of sugar per flower within each OSR breeding system. For conventional OSR varieties, regression analyses indicated that the most parsimonious model explained 44.3% of the variance and that the model was a significant predictor of sugar per flower ( $F_{3,36} = 11.32$ ,  $p < 0.001$ ). VPD ( $\beta = -0.82296$ ,  $p < 0.001$ ) and early vigour ( $\beta = 0.12628$ ,  $p < 0.05$ ) contributed significantly to the model. Although winter hardiness had only a marginal effect, it was included in the model based on AIC comparisons ( $\beta = 0.22494$ ,  $p < 0.1$ ). The final predictive model was:

$$\text{Sugar (mg)} = -2.17544 + (-0.82 * \text{VPD}) + (0.13 * \text{early vigour}) + (0.22 * \text{winter hardiness}) \quad (4)$$

For hybrid varieties, the most parsimonious model explained 51.2% of the variance and was a significant predictor of sugar ( $F_{2,33} = 19.37$ ,  $p < 0.001$ ). Both VPD ( $\beta = -0.76427$ ,  $p < 0.001$ ) and stem stiffness ( $\beta = 0.09746$ ,  $p < 0.05$ ) contributed significantly to the model.

The final predictive model was:

$$\text{Sugar (mg)} = 0.16517282 + (-0.76 * \text{VPD}) + (0.097 * \text{stem stiffness}) \quad (5)$$

### 3.4.2. Pollen per Flower

Multiple linear regression was also performed to determine whether agronomic traits could be used to predict the number of pollen grains per flower within each OSR breeding system. The most parsimonious regression model explained 24.5% of the variance for conventional varieties and was a significant predictor of pollen quantity ( $F_{1,28} = 10.41$ ,  $p < 0.005$ ). Earliness of maturity contributed significantly to the model ( $\beta = -24180.56$ ,  $p < 0.005$ ). The final predictive model was:

$$\text{pollen quantity} = 358181.60 + (-24180.56 * \text{earliness of maturity}) \quad (6)$$

For hybrid varieties, the regression model explained 38.6% of the variance but was not a significant predictor of pollen quantity ( $F_{1,25} = 2.044$ ,  $p = 0.165$ ). The best fit model using AIC was:

$$\text{pollen quantity} = 160953.2 + (11779.8 * \text{resistance to lodging}) \quad (7)$$

## 4. Discussion

### 4.1. Overview

This study is the first to use readily available agronomic trait data to predict floral resource availability in winter-sown OSR varieties. Results demonstrate that routinely monitored agronomic traits influence the quantity of sugar and pollen that a plant produces, indicating the potential to rapidly assess floral resources based on such traits. Varietal differences in agronomic traits make it possible to predict sugar content in future conventionally bred and hybrid OSR varieties and pollen quantity in conventionally bred varieties without the targeted sampling of floral resources.

### 4.2. Impact of Environmental Factors on Nectar Resources

Short-term climatic changes before sampling affect the sugar content of nectar significantly. In agreement with previous research, an inverse relationship was detected between nectar sugar content and temperature [57,58]. In contrast with temperature, humidity has a positive relationship with sugar content. Environmental impacts on sugar content occurred immediately before sampling, indicating a post-secretory rather than a physiological response. Corbet, et al. [59] found that low humidity caused water evaporation from post-secretory nectar, resulting in a higher concentration of sugar, and high humidity caused dilution. It is possible that the positive relationship between sugar content and humidity may simply result from a sampling artefact. The more humid conditions are during collection, the more diluted the nectar will become. Therefore, sampling total sugar content would be more effective in damper conditions since any small amount of nectar remaining in the flower following micro-pipetting would contain lower sugar concentrations in damper conditions.

Vapour pressure deficit (VPD) is calculated using temperature and relative humidity. Although it affects sugar content similarly to temperature, it explains more of the variance (32%) than either temperature or humidity (27% and 29%, respectively). While the impact of temperature is commonly considered when sampling plant nectar [60], this research indicates that VPD is a marginally better predictor of sugar content. With VPD being easily

calculated from temperature and humidity, we recommend taking it into account in future floral research on resource availability.

#### *4.3. Impact of Breeding System on Floral Resources*

In agreement with previous research in controlled environments, hybrid varieties produced more sugar per flower than conventional varieties [44]. However, these results are not consistent with field studies, which indicated no differences between the sugar content of hybrid and conventional varieties [61,62]. The influence of short-term environmental effects may be one possible explanation. Pernal and Currie [61] sampled multiple times during the day (08:00, 11:00, 14:00 and 16:00 hrs) over four weeks. Although their analysis included sampling time and day, it did not account for variable environmental conditions during sampling. Under the controlled conditions of Carruthers et al. [44], the glasshouse study would be less affected by temperature and humidity. As previously mentioned, VPD has a significant effect on sugar content in OSR and may explain the conflicting results between the studies.

Conventional and hybrid varieties of OSR produce a similar number of mean pollen grains per flower, with a difference of only 2% across breeding systems. However, within breeding systems, varietal differences are high. In conventional varieties, the lowest-performing variety, in terms of mean pollen grains per flower, produces only 55% of the highest-performing variety. Hybrid varieties show less variability than conventional varieties in pollen grains per flower, with the lowest-performing variety producing 78% of the highest-performing hybrid variety.

#### *4.4. Impact of Agronomic Traits on Floral Resources*

Mass-flowering crops such as OSR provide a vital food source for all flower-visiting insects, particularly social insects in the early stages of their lifecycle when colony establishment is underway [30,32]. In agreement with our findings, floral resource availability varies significantly between OSR varieties [45,61]. Breeders produce varieties based on the heritable traits of the parent plants, and field trials focus primarily on measuring performance based on yield potential, seed quality, disease resistance and desirable agronomic traits [63]. Therefore, floral resource availability is not routinely collected in varietal trials. To do so would require specialist equipment and training and involve considerable work by trials managers. The ability to predict floral resources using already available agronomic traits would allow inclusion into varietal recommendation lists and provide growers with the opportunity to make an informed varietal selection.

#### *4.5. Model Application*

Using agronomic traits obtained during national testing alongside floral resource data extracted from field sampling, we created models to predict floral resource availability across OSR varieties. In models for predicting sugar content, VPD had a more substantial effect on sugar per flower than individual agronomic traits in both breeding systems, highlighting the importance of considering environmental factors when sampling nectar.

For sugar content in conventional varieties, early vigour and winter hardiness were the main agronomic trait predictors, with both traits positively influencing flower sugar content. This suggests that varieties with a higher tolerance to stressful environmental factors during the early season allocated more resources to pollinators by offering increased sugar per flower. Similarly, for hybrid varieties, the strength of the stem during maturity is important to sugar availability, and resistance to lodging during the flowering stage is an important predictor for pollen quantity. These agronomic traits are likely to be a proxy for the plant's overall health during the flowering period, with investment in nectar and pollen production being more viable in healthier plants. Varieties that show higher early vigour may also benefit from increased soil moisture later in the season. Early leaf development accelerates canopy closure in water-limited environments and reduces the water evaporation of soil [64,65]. With drought having an adverse effect on nectar volume

or concentration in some plant species [66], this reserve of water may benefit later-season plant development in OSR, such as sugar production. With winter hardiness and early vigour being 'desirable' OSR traits to growers, the addition of increased floral resources is a bonus. Growers who select these varieties, therefore, benefit in two ways. Besides having a more robust, healthier crop, the increase in food availability could encourage pollinators, potentially increasing yield through enhanced pollination.

If early season growth and resultant plant health contribute to increased sugar content, varieties that mature early have the opposite effect on pollen quantity. Conventional varieties that matured earlier produced fewer pollen grains per flower, suggesting that resources are allocated into growth rather than pollen production. Early maturity is considered a 'desirable' trait by growers as it increases the likelihood of getting the following crop sown immediately after harvest. Harvesting schedules do not allow for much leeway, so early maturity is less likely to result in the harvesting of under-ripe seed pods. Immature seeds may weigh less and suffer from reduced oil content—the two metrics that contribute to the economic value of OSR seeds [13,67]. This highlights a potential trade-off between early maturation and the production of pollen.

From a physiological perspective, we could consider the allocation of a plant's resources. Varieties that display favourable agronomic traits result in stronger plants during the peak-flowering period. Therefore, a healthier plant will be better equipped to deal with the numerous challenges it may encounter during a growing season (e.g., water stress and disease), allowing for a more significant investment of resources into reproduction. Distributing resources between the functional traits for growth and reproduction is considered a central theme in life-history strategy [68]. The misallocation of resources can directly influence plant development during maturity [69].

The models created to predict sugar content explained more of the variance than those created for pollen, although the influence of VPD largely explained this. To increase the accuracy of predictions, the method in which trial managers collect the agronomic trait data may need revision. During national testing in the UK, these traits are given a value as a comparison against other varieties, consequently generating ordinal rather than interval data. Baude, et al. [46] predicted nectar productivity for plant species using plant trait data collected from an online database and included physical measurements such as plant height, breeding system and length of the flowering period. By basing regression models on measurement data rather than comparison data from agronomic traits, it may be possible to build models with a more substantial predictive power. However, models based on actual field measurements collected on an interval scale would require the lengthy collection of agronomic trait data to enable prediction in future varieties.

Although this study uses sugar weight and pollen grains as a proxy for floral resources, the resource value for pollinators is influenced by many factors such as the duration of flowering and floral density. In mass-flowering crops such as OSR, which flower when pollinator populations are low, floral density becomes less important than sugar concentration. With little competition for resources, having more resources per flower is more beneficial to foraging dynamics than more flowers. Another consideration is the constituents of the resources, such as micro-nutrient availability. Filipiak [70] reports that pollen quality is more important than quantity for bee growth and development.

## 5. Conclusions

In this preliminary study on 19 OSR varieties, we have demonstrated that sugar and pollen quantity can be predicted using agronomic trait data collected during national testing. These models are future-proof in allowing us to rapidly predict floral resource availability in new varieties of oilseed rape. Predicting floral resources is likely to benefit both insect pollinators and also growers through safeguarding pollination services. Our research indicates that agronomic traits that are beneficial to growers (e.g., early vigour, winter hardiness and stem strength) are also favourable to pollinators with OSR varieties exhibiting such traits producing nectar with higher sugar content. With oilseed rape yields

increasing as the number of pollinator visits increase [15,71], growers with access to a large and diverse pollinator community, whether from managed honey bees or abundant natural habitat for wild pollinators, are likely to derive the greatest agronomic benefits [13,72]. With gaps in forage limiting pollinator populations [35,73], profitable OSR varieties should be integrated alongside agri-environmental measures (e.g., hedgerow creation and restoration, floral-rich field margins) to ensure forage stability and maintain pollinator assemblages throughout the season, as well as providing additional resources such as nesting and hoverfly larval resources. Providing growers with information on the floral resource profitability of OSR varieties will enable them to make informed choices when selecting varieties with positive implications for both crop yield and insect pollinators.

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